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RRB - JE

CIVIL

Railway Recruitment Board

Volume - 10

Transportation Engineering

SIERRA
INNOVATIONS

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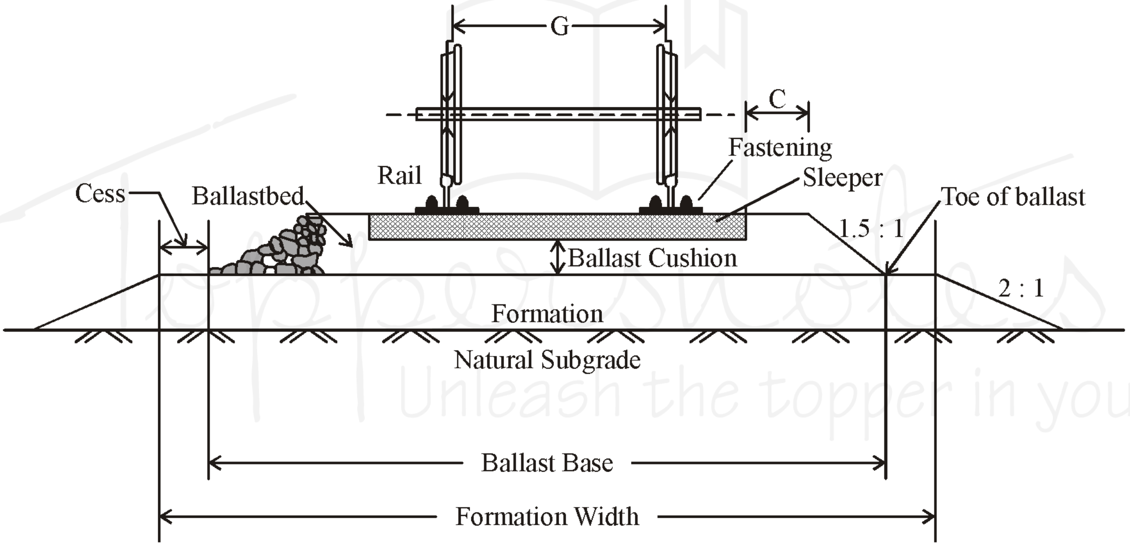
S.No. Topic **Page No.**

RAILWAY ENGINEERING

THEORY

Railway track is called permanent way to distinguish it from the temporary tracks laid for conveyance of earth and materials on construction works. Permanent way is the combination of rails, fitted on sleepers with the help of fixtures and fastenings and resting on ballast and subgrade is called the railway track or permanent way.

2.1 TRACK STRUCTURE

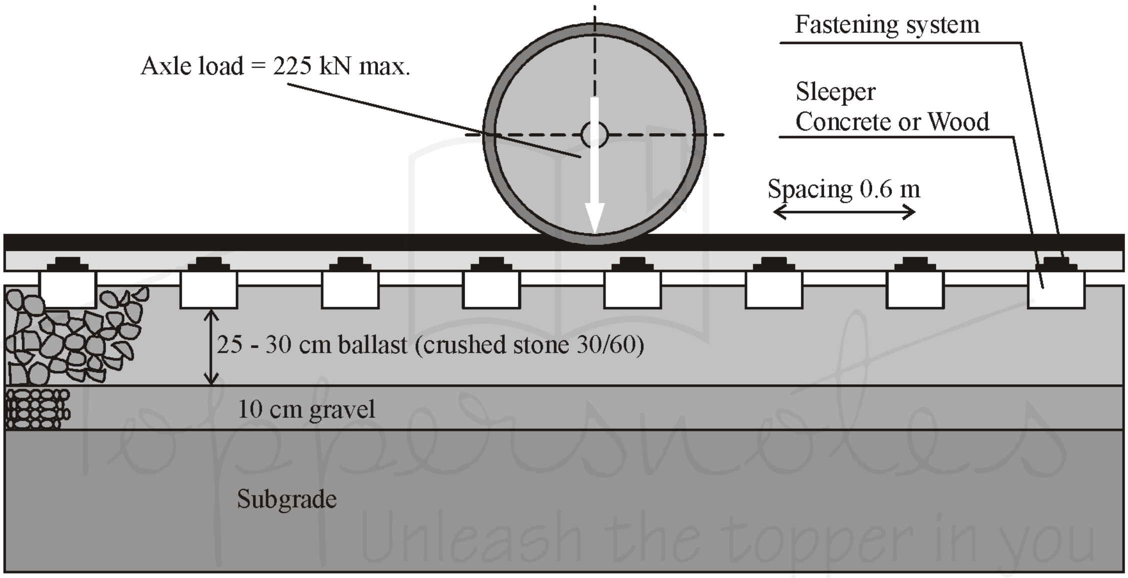


2.2 TRACK COMPONENTS

- **Gauge :** The distance between the running or gauge faces of the two rails measured 14 mm below the top surface
- **Rails :** Rails act as girders to transmit the wheel load to the sleepers. Rails are joined in series by welding a few of them (5 of them) and the welded lengths are joined by fish plates and bolts. Rails are fixed to sleepers by different types of fixtures and fastenings.
- **Sleepers :** Sleepers hold the rails in proper position with respect to their proper tilt, gauge and level and transmit the load from rails to the ballast. These sleepers are suitably spaced, packed and boxed with ballast. The typical length of a BG sleeper is 2.7 m.
- **Ballast :** Ballast is a high quality crushed stone with desired specifications placed directly below the sleeper. Ballast distributes the load over the formation and holds the sleepers in position and also functions as drainage layer.

- **Formation :** Formation is the compacted and prepared subgrade which is the part of embankment or cutting. Natural subgrade is the soil in the natural ground on which the track rests.
- **Ballast cushion :** The depth of ballast below the bottom of the sleeper, normally measured under rail seat is termed as ballast cushion.
- **Ballast shoulder :** Ballast provided beyond the sleeper edge is termed as ballast shoulder (shown as C in Fig., typically 0.35 m in a BG track).
- **Ballast Base :** It is the bottom width of ballast-bed (typically 4.4 m in a BG track).
- **Formation width :** It is the top width of embankment or bottom width of cutting (Typically 6.1 m in a BG track).
- **Cess width :** Width of formation beyond the toe of ballast is termed as cess width.

2.3 CONVENTIONAL TRACK STRUCTURE



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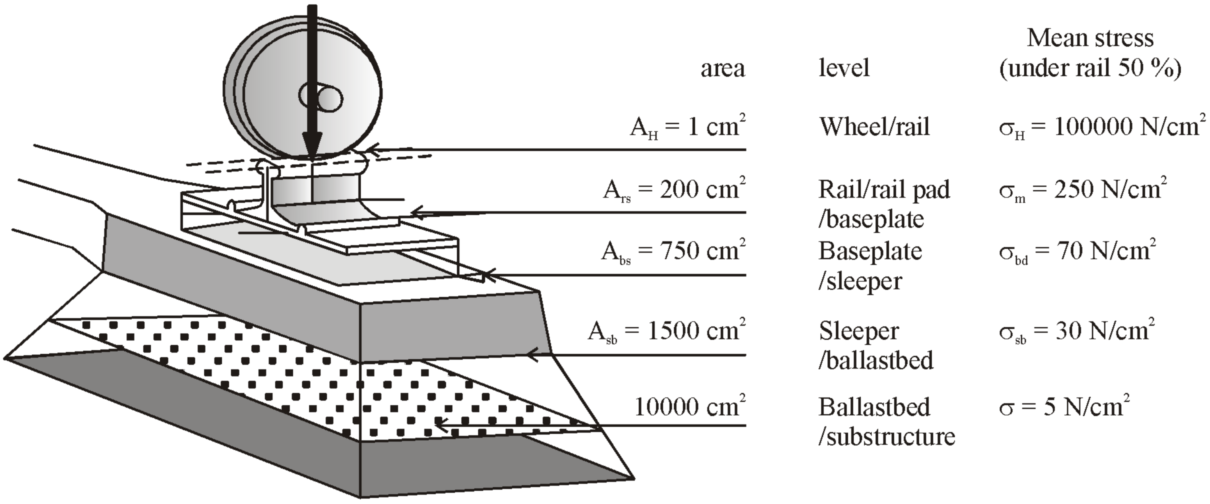
2.4 LOAD-BEARING FUNCTION OF THE TRACK

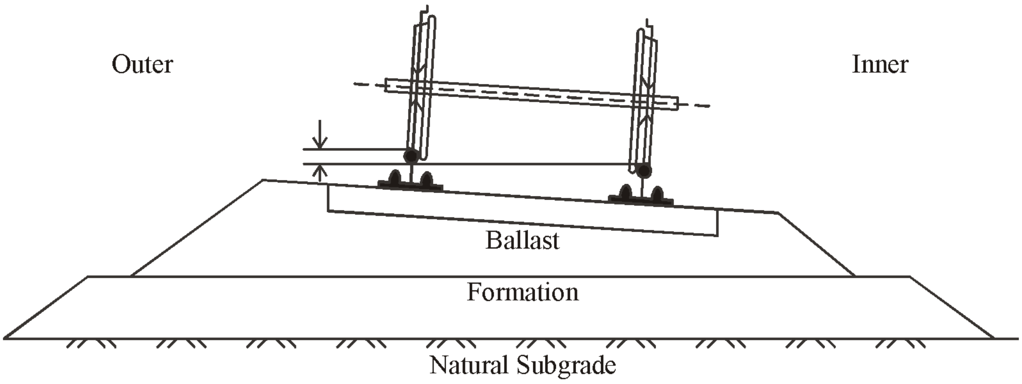
Axle : P = 200 kN
Wheel : Q = 100 kN



area	level	Mean stress (under rail 50 %)
$A_H = 1\ cm^2$	Wheel/rail	$\sigma_H = 100000\ N/cm^2$
$A_{rs} = 200\ cm^2$	Rail/rail pad /baseplate	$\sigma_m = 250\ N/cm^2$
$A_{bs} = 750\ cm^2$	Baseplate /sleeper	$\sigma_{bd} = 70\ N/cm^2$
$A_{sb} = 1500\ cm^2$	Sleeper /ballastbed	$\sigma_{sb} = 30\ N/cm^2$
$10000\ cm^2$	Ballastbed /substructure	$\sigma = 5\ N/cm^2$

2.5 TRACK ON A CURVE

Superelevation is maintained by varying the ballast cushion and the formation is kept level. Minimum cushion is maintained at the inner rail, while the outer rail gets more ballast cushion.



2.6 VARIOUS GAUGES ON WORLD RAILWAYS

The most widely used gauge in the world is the standard gauge.

Type of Gauge	Gauge Distance	Percent of Total Length	Countries
Standard Gauge	1.435	62	Europe, USA, China, Australia, Persia, etc.
Broad Gauge (BG)	1.676	6	India, Pakistan, Sri Lanka, Argentina, Brazil
Metre Gauge (MG)	1.000	9	India, France, Switzerland, Argentina
Other Gauges	Different Gauges	23	Various Countries

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2.7 LENGTH OF INDIAN RAILWAY TRACK

Type of Track	Length*, km
Broad Gauge (BG)	46806
Metre Gauge (MG)	13290
Narrow Gauge (NG)	3124
total track route km	63220
Total running track km	83859
Total track km	108486

- **Route kilometer :** This is the route length of railway between origins and destinations.
- **Running track kilometer :** This is the length of running track on a route. On a route with double track, the running track kilometer is about twice the route kilometer.
- Total track kilometer is the physical length of track available. This length is arrived at after giving due weightage for the length of track on track junctions, sidings, etc., and adding it to the running track kilometer.

2.7.1 Advantage of Larger Gauge

- Larger the gauge, greater is the traffic capacity, speed and safety.
- However, larger gauge requires flatter gradients and curves.
- Though the cost of construction increases with gauge, in many cases the increase in cost is marginal.

2.8 SELECTION OF GAUGE

2.8.1 Cost of Construction

- There is proportional increase in the cost of acquisition of land, earthwork, rails, sleepers, ballast, and other track items with gauge
- The cost of bridges, tunnels and culverts increases only marginally with gauge
- The cost of station buildings, platforms, signals etc., is same more or less for all gauges
- The cost of rolling stock also increases marginally for larger gauges
  - ✧ Volume and nature of traffic
  - ✧ Speed of movement (wheel diameter = 0.75 × Gauge)
  - ✧ Development of areas
  - ✧ Physical features of the country

2.8.2 Uniformity of Gauges

- Gauge to be used in a particular country should be uniform throughout as far as possible.
- Whenever there is change of gauge, there has to be transshipment of passengers and goods.
- This causes duplication of equipment, surplus wagons and locomotives.
- Uniformity of gauge is ideal for any country.
- In India, the uniformity of gauges is being achieved by a gradual conversion of MG to BG.
- In view of its heavy financial implications the progress has been slow.

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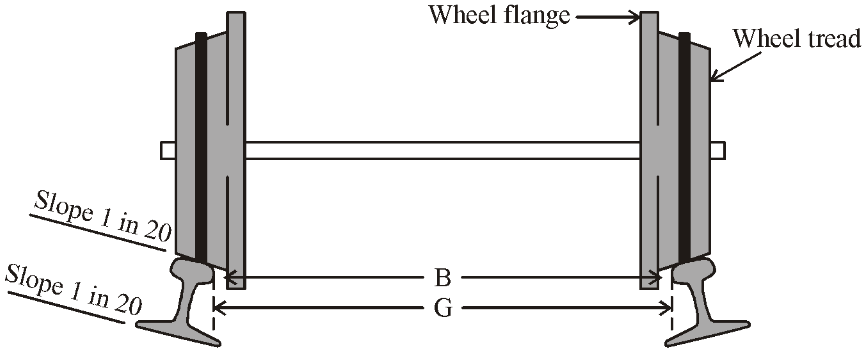
2.8.3 Progress of Gauge Conversion in India

Period	Length of Conversion (km)
1947 – 1993	2500 (approximate)
1993 – 1997	6897
1997 – 2001	1892
2001 – 2004	1895

2.9 CONING OF WHEELS



The wheels of locomotive are not flat but sloped or coned at a slope of 1 in 20. The distance between inside edges of wheel flanges (B) is generally kept less than the gauge (G). This results in a gap of 1 cm between flange and running face of rail.

2.9.1 Tilting of Rails

If the rails are laid flat, coning of wheels will subject the rails to stress concentration and eccentric loading at the inner edge. This would create problems in both rail design and maintenance. To avoid this, rails are not laid flat but are tilted inwards at a slope of 1 in 20. The rail is tilted by adding the wooden sleeper or by providing canted bearing plates.

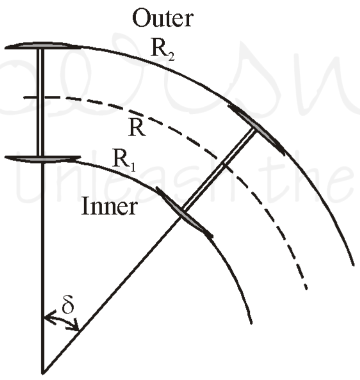
2.9.2 Behaviour of Coned Wheels on Straight Track

On a level track as soon as the axle moves towards one rail, the diameter of the wheel tread over the rail increases while it decreases over the other rail. The wheels have to tread unequal distance on the rails. The wheels therefore retreat till they are at the central position again, because of rigid wheel base. If there is no coning, the side movement would have continued and the flange of the wheel would have come in contact with the side of rail, causing jerks and making the ride uncomfortable.

2.9.3 Behavior of Coned Wheels on Curved Track

On curves, the outer rail is longer than the inner rail. Due to the action of centrifugal force on a curve, the vehicle tends to move out. The coning helps the wheels to take up position, where greater diameter is available to tread longer distance of outer rail and smaller diameter to cover the smaller distances of inner rail. This reduces slipping and skidding of wheels.

2.9.4 Slip on Curves



$$G = R_2 - R_1$$

R_1 = radius of inner rail
R_2 = radius of outer rail
R = radius of centre line
G = Gauge distance
δ = angle at the centre in radians
θ = angle at the centre in degrees

$$\begin{aligned}\text{Slip} &= (R_2\delta - R_1\delta)\\ &= G\delta = [(\pi\theta / 180)]\ (G)\\ &= 0.029\theta\end{aligned}$$

The approximate slip on BG curve is 0.029 m per 1° of curve.

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2.10 CLASSIFICATION OF INDIAN RAILWAY LINES

2.10.1 Broad Gauge Routes

Group A Lines : Sanctioned speed of 160 km/hr

Group B Lines : Sanctioned speed of 130 km/hr

Group C Lines : Lines on suburban sections of Mumbai, Kolkata and Chennai

Group D Lines : Sanctioned speed of 100 km/hr

Group E Lines : Meant for other sections and branch lines

2.10.2 Metre Gauge Routes

Q routes : Maximum permissible speed of more than 75 km/hr. Traffic density on these lines is generally more than 2.5 GMT (Gross Million Tonnes per km per annum).

R routes : Speed potential of 75 km/hr. Traffic density of more than 1.5 GMT.

S routes : Speed potential of less than 75 km/hr and traffic density of less than 1.5 GMT.

2.11 GRADIENTS

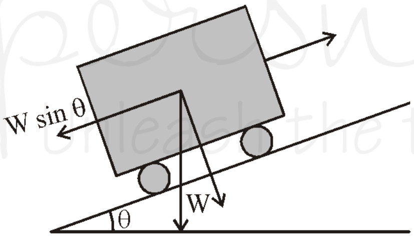
2.11.1 Ruling Gradient

The ruling gradient is the maximum gradient that exists in a section. The designer attempts to fix the grade line of the formation by keeping the gradients within the ruling gradient. Ruling gradient determines the maximum load that the engine can haul on the section.

If W = weight of train

θ = angle of slope

$$\text{Extra pull required} = W \sin\theta \approx W \tan\theta = W \times \text{gradient}$$



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Indian railways does not specify any fixed ruling gradient due to enormous variations in

- Topography
- Traffic plying on various routes
- Speed and type of locomotive

Generally the following ruling gradients are adopted

- In plains : 1 in 150 to 1 in 200
- In hilly terrain : 1 in 100 to 1 in 150

As a rule once the ruling gradient is specified for a section there should be no grade steeper than this ruling gradient.

2.11.2 Momentum Gradient

These gradients are steeper than the ruling gradients. These are allowed because they are positioned in such a way that they do not determine the maximum load of the train. The train before approaching them acquires sufficient momentum to negotiate them. A raising gradient (steeper than the ruling gradient) followed by a falling gradient is an example for momentum gradient. The train negotiates this steeper raising gradient with the help of the momentum acquired while coming down the falling gradient. However, trains can not be stopped, and no obstacles in the form of signals can be located in the stretch of momentum gradient.

2.11.3 Pusher or Helper Gradient

In hilly terrain, some times, gradients steeper than ruling gradient are permitted to reduce the length of track and overall cost. On sections where the gradient is steeper than the ruling gradient, the trains are pushed by additional engine. Such gradients where extra engine becomes necessary to push a full load train are termed as pusher gradients.

Example of pusher gradient : 1 in 37 on BG track on Western Ghats.

A helper gradient of 1 in 75 to 1 in 100 with additional engine is generally used.

2.11.4 Gradients in Station Yards

At station yards, flatter gradients are used for two reasons

- Prevent movement of standing vehicles
- Trains have to over come additional resistance when they start from stopped position

However, tracks will have certain minimum gradient at station yards, to take care of drainage

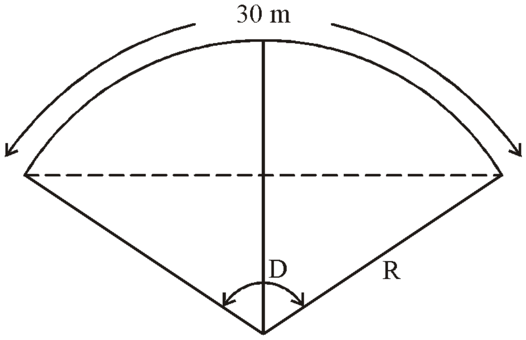
- Maximum gradient 1 in 400
- Minimum gradient 1 in 1000

2.12 GRADE COMPENSATION

When a gradient is on a curve, the train has to overcome curve resistance in addition to the grade resistance. Therefore, in order to avoid resistances beyond allowable limits, the gradients are reduced on curves and this reduction in gradient is known as grade compensation on curves. Indian Railways compensates the gradients on curves to the following extent

- On BG tracks, 0.04% per degree of the curve
- On MG tracks, 0.03% per degree of the curve
- On NG tracks, 0.02% per degree of the curve

2.13 DEGREE OF THE CURVE



$$R \times (D/180) \times \pi = 30$$

$$R = (30 \times 180)/(\pi D) = 1718.87/D$$

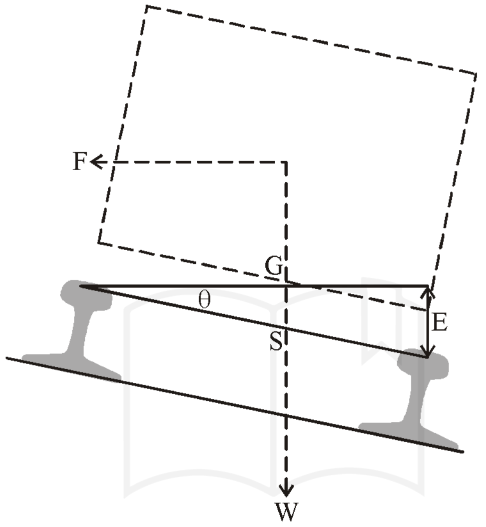
$$R \approx 1720/D$$

Railway curves are generally designated by the degree of the curve instead of radius. The angle subtended at the centre by a curve of length 30 m is the degree of that curve.

2.14 MAXIMUM PERMISSIBLE DEGREE OF CURVES

Gauge	On Plain Track		On Turnouts	
	Max. Degree	Min. Radius (m)	Max. Degree	Min. Radius (m)
BG	10	175	8	215
MG	16	110	15	115
NG	40	45	17	105

2.15 SUPERELEVATION OR CANT



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$$F = \frac{Wv^2}{gR}$$

$$F \cos \theta = W \sin \theta$$

$$\frac{F}{W} = \tan \theta = \frac{E}{G}$$

$$\frac{v^2}{gR} = \frac{E}{G}$$

$$E = \frac{Gv^2}{gR}$$

F = Centrifugal Force

W = Weight of locomotive

E = Cant

v = Speed, m/s

2.16 EQUILIBRIUM SPEED

The superelevation computed by above equation does not consider the mobilization of lateral friction. Therefore, at speed v, the centrifugal force is completely balanced by the component of weight. At this speed the weight will be equally distributed between the wheels. This speed at which the centrifugal force is completely balanced by the cant provided is termed as equilibrium speed.

2.17 CANT DEFICIENCY AND CANT EXCESS

When a train moves at a speed greater than the equilibrium speed, the centrifugal force will not be fully balanced by the weight component. The train is said to experience cant deficiency. When a train moves at a speed less than the equilibrium speed, the train experiences cant excess. The difference between the equilibrium cant necessary for the maximum permissible speed on a curve and the actual cant provided is termed as cant deficiency (C_d). The difference between the equilibrium cant required for the low speed (goods) train and the actual cant provided is the cant excess (C_e).

2.18 LIMITING VALUES OF C_d AND C_e

Cant deficiency and cant excess values are limited

- To minimise the discomfort to passengers
- To minimise the unbalanced lateral forces and unbalanced distribution of wheel loads
- To limit unbalanced lateral acceleration for the requirements of safety and Stability.

Gauge	Group	C_d (mm)	C_e (mm)
BG	A and B	75 or 100*	75
	C, D & E	75	75
MG	All routes	50	65
NG	All routes	40	-

2.19 MAXIMUM SUPERELEVATION

In addition, the maximum superelevation is limited to take care of the stability of standing vehicles on curves. World wide, the maximum value of super elevation adopted is 1/10 to 1/12 of gauge

Gauge	Group	Limiting Values of Cant (mm)	
		Under normal conditions	With special Permission of CE
BG	A	165	185
	B and C	165	-
	D and E	140	-
MG	-	90	100
NG	-	65	75

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2.20 LENGTH OF TRANSITION CURVE

1. Based on allowable rate of change of cant or cant deficiency

$$L = (C_a/\gamma)\, V_m$$

$$L = (C_d/\gamma)\, V_m \qquad ...(1)$$

where, L = Length of transition curve, m

V_m = maximum permissible speed, m/s

C_a = actual cant provided, mm

C_d = cant deficiency, mm

γ = allowable rate of change of cant or cant deficiency, mm/sec

2. Based on allowable cant gradient

$$L = NC \qquad ...(2)$$

where, 1 in N is the allowable cant gradient

3. Based on allowable rate of introduction of centrifugal acceleration

$$L = (V_m^3)/(CR) \qquad ...(3)$$

where C = allowable rate of centrifugal acceleration

R = radius of the horizontal curve

Indian Railways uses cubic parabola as transition curve and its length is determined as the maximum of equation (1), (2) and (3).

2.20.1 Limiting Values for Design Parameters of Transition Curve

Parameter	Limiting values	
	BG	MG
Rate of change of C_a or C_d γ	Desirable – 35 mm/s Maximum – 55 mm/s	Desirable – 35 mm/s Maximum – 35 mm/s
Cant gradient, 1 in N	1 in 720 (1 in 360 in exceptional cases)	1 in 720
Rate of introduction of centrifugal acceleration, C	0.3048 m/s^3	0.3048 m/s^3

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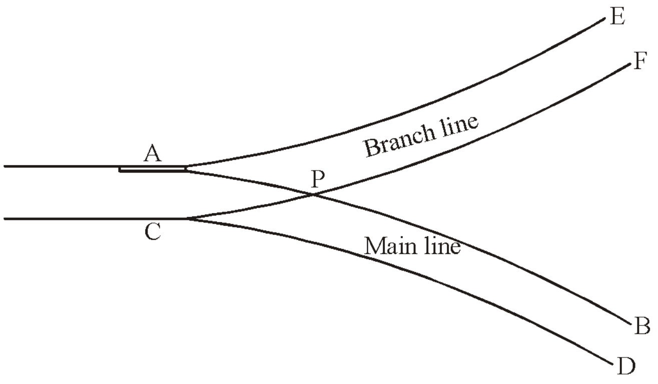
2.21 MAXIMUM PERMISSIBLE SPEED ON CURVE

- Maximum Sanctioned speed on the section.
- Maximum speed worked out based on the consideration of cant deficiency.
- Maximum speed worked out based on the speed of goods train and consideration of cant excess.
- Maximum speed worked out based on the length of transition curve.

2.22 NEGATIVE SUPERELEVATION

- Situation: Main line is on a curve and has a turnout with opposite curvature leading to a branch line.
- If positive superelevation is provided on main line, then the branch line will have a negative superelevation of the same amount.
- To take care of this situation, the speeds on both the lines are restricted.



2.22.1 Computations for Negative Superelevation

Calculate the equilibrium SE (C_m) required on branch line for the permissible maximum speed on BL. Find the actual SE (C_a) on BL by subtracting cant deficiency (C_d) from C_m. As the speed is limited on BL, C_d will be more than C_m. Therefore the actual SE on BL will be negative. The actual SE on main line will be (–) C_a. The maximum speed on ML is calculated by adding C_d to the positive SE provided on ML.

2.23 POINTS AND CROSSINGS

Points and crossings are the arrangements required for constructing track junctions enabling trains to move from one track to another. Turnout is a simple track junction wherein a branch line is taken off from a main line by proper arrangement of points and crossings.

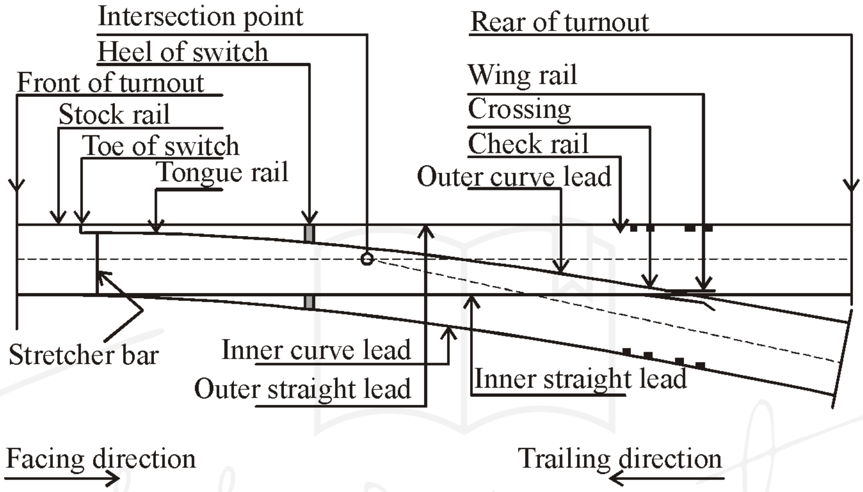


Fig. : Turnout

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2.23.2 Facing and Trailing Points

Facing direction and facing points

- If one stands at the toe of switch and looks towards the crossing, that direction is called facing direction
- If a train moves from toe of switch to the heel of switch, then the points are referred to as facing points for that train.

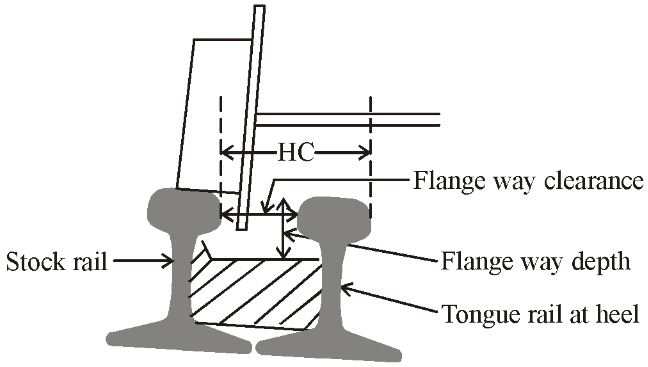
Trailing direction and trailing points

- If one stands at the crossing and looks towards the points, that direction is called trailing direction
- If a train moves from heel of switch to the toe of switch, then the points are referred to as trailing points for that train.

2.23.3 Components of a Turnout

- A pair of points or switches
- A pair of stock rails
- A pair of tongue rails
- A pair of heel blocks
- Gauge tie plate, stretcher bars, slide chairs
- Point rail, splice rail, two wing rails, two check rails
- Four sets of lead rails

2.23.4 Cross Section at Heel of Switch



2.23.5 Terms Relating to Switch

Heel block : The cast iron block inserted between the tongue rail and the stock rail at the heel of switch is called heel block.

Distance block : The block inserted between check rail and the running rail at the crossing to provide the required flange way is called distance block.

Heel Clearance (HC) or heel divergence : It is the shortest distance from gauge line of stock rail to gauge line of tongue rail at the heel of a switch; i.e., the clear distance between stock rail and tongue rail plus the rail head width.

Flange way Clearance (FC) : This is the distance between the adjacent faces of the stock rail and the tongue rail.

$$HC = FC + \text{rail head width}$$

Flange way depth : The vertical distance between top surface of the running rail to the top surface of the heel block.

Through of switch : The distance by which the toe of the tongue rail moves sideways to provide a path for the desired direction over the turnout.

Specifications on Switch Dimensions :

Dimension	Broad Gauge		Metre Gauge	
	Maximum	Minimum	Maximum	Minimum
Heel Clearance	137	133	121	117
Flange way clearance	48	44	44	41
Through of switch	115	95	100	89

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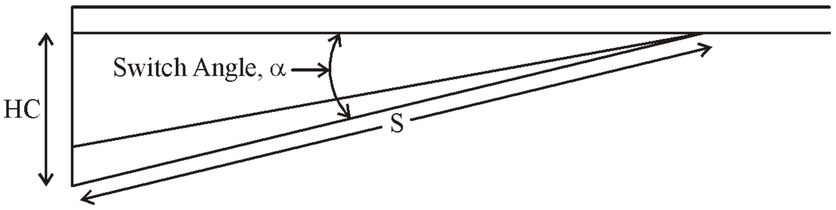
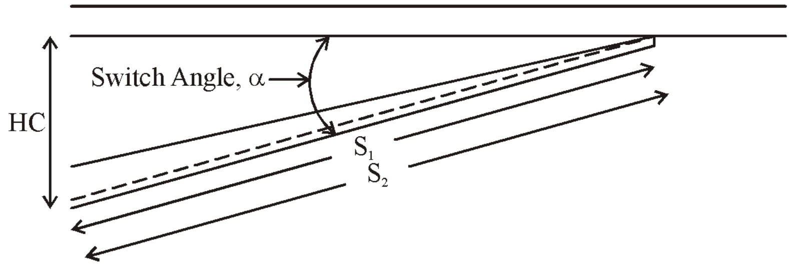
2.23.6 Switch Angle

This is the angle between the running faces of stock rail and tongue rail when the switch is in closed position

Case-I: When thickness of tongue rail at toe = 0



$$\sin \alpha = HC/S$$



Case-II: When thickness of tongue rail at toe = t

$$\sin\alpha = (HC-t)S_1$$

or

$$\sin\alpha = HC/S_2$$

2.24 BASIC COMPONENTS OF CROSSING

Crossing is the arrangement that facilitates movement of wheel flanges when two rails cross. Basic components are

- Point rail and splice rail
- Two wing rails
- Two Check rails
- Chairs at crossing blocks
- **Crossing Angle :** The angle between the running faces of the point rail and splice rail.
- **ANC and TNC :** The point rail is provided with a blunt point, which is the Actual Nose of Crossing (ANC). The sharp imaginary point where the gauge faces of point rail and splice rail meet is called Theoretical Nose of Crossing (TNC).

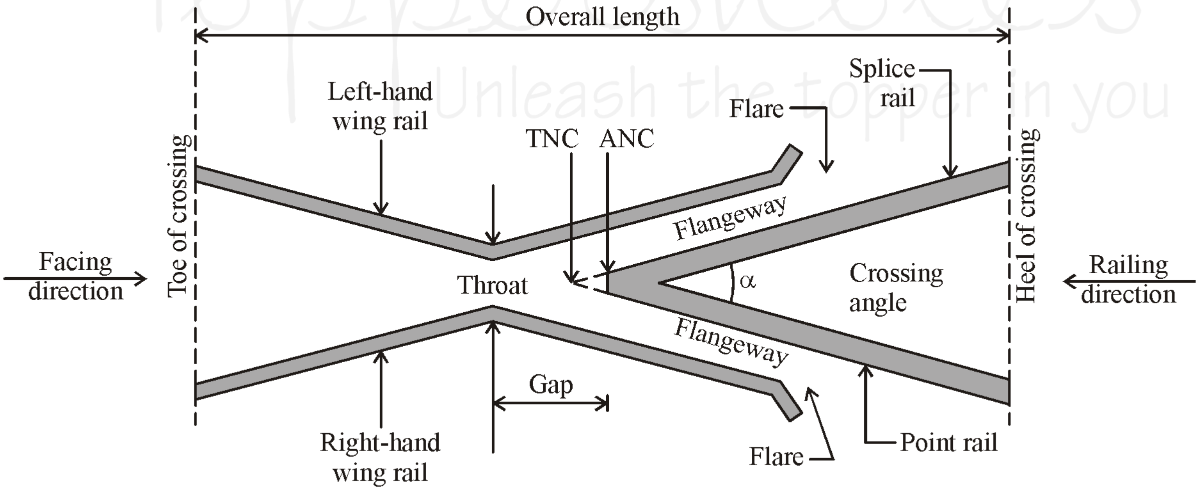


Fig. : Details of a Crossing

2.24.1 Crossing Number (N)

Crossing angle is represented as crossing number. There are three methods of measuring crossing angle by means of crossing number.

(a) Right angle or Cole's method : This method is used on Indian Railways. Crossing number (N) is the length of splice rail for unit spread. N is measured along the base of right angled triangle.

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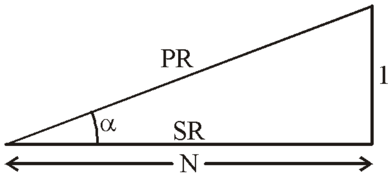
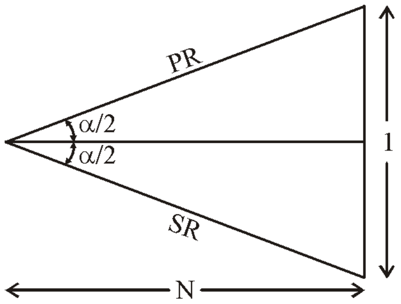


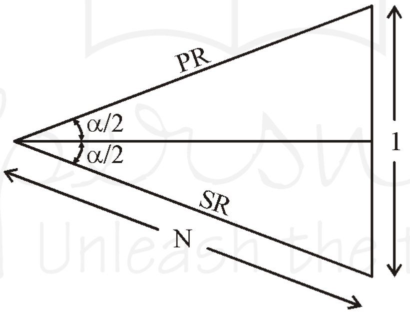
Therefore, $N = \cot \alpha$

(b) **Centre Line Method :** This method is used in UK and USA. In this method, crossing number is measured along the centre line of the crossing as shown above.



Therefore, $N = \frac{1}{2} \cot (\alpha/2)$

(c) **Isosceles Method :** In this method, the crossing number, N, is measured along one of the sides of isosceles triangle formed by SR and PR for unit spread.



$$\sin\frac{\alpha}{2} = \frac{1/2}{N} = \frac{1}{2N}$$

$$N = \frac{1}{2\sin\frac{\alpha}{2}}$$

2.25 STANDARD TURNOUTS

Turnouts are designated by their crossing number. Standard turnouts on Indian Railways are

- 1 in 8.5 turnouts are used for goods trains.
- 1 in 12 and 1 in 16 turnouts are used for passenger trains.
- 1 in 20 and 1 in 24 turnouts have also been designed by RDSO to permit higher speeds.

2.25.1 Notations used in Turnout Design

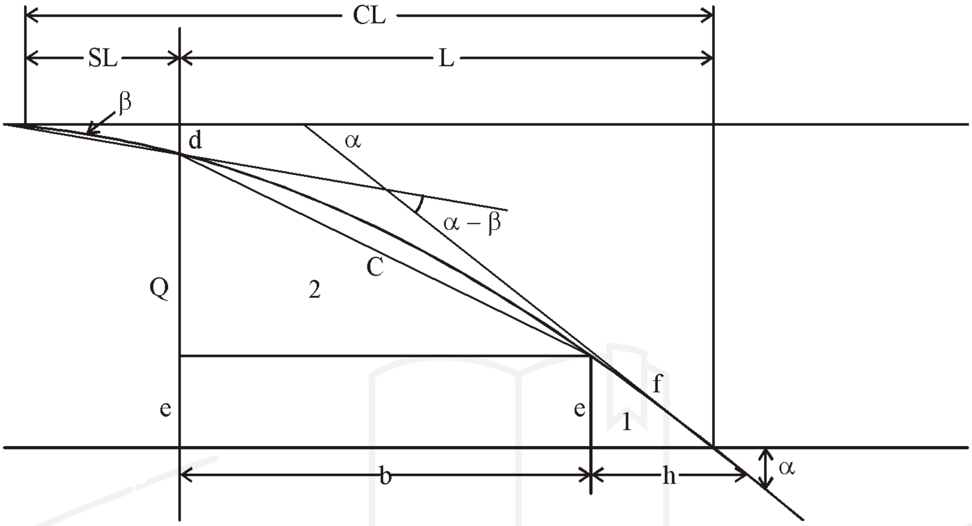
Switch Lead (SL) : This is the distance between the tangent point and the heel of switch measured along the length of main track.

Lead (L) : This is the distance between theoretical nose of crossing and heel of switch measured along the length of main track.

Curve Lead (CL) : This is the distance between the tangent point and theoretical nose of crossing measured along the main track.

$$L = CL - SL$$

2.25.2 Turnout Design (IRS Method)



α = angle of switch

β = angle of crossing

d = heel divergence

G = gauge distance

R = radius of the turnout

f = straight arm of crossing

C = length of chord

SL = switch lead

L = lead

CL = curve Lead

In Δ_1

$$h = f \cos \alpha$$

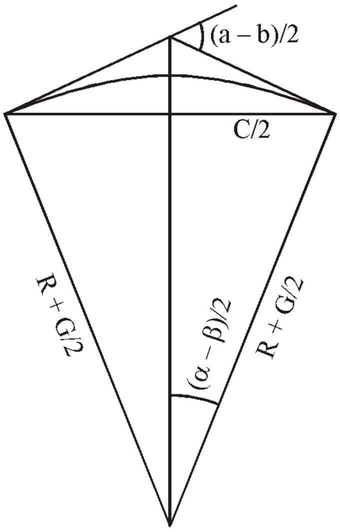
$$e = f \sin \alpha$$

$$Q = G - (d + e)$$

In Δ_2

$$b = \frac{Q}{\tan\left(\frac{\alpha+\beta}{2}\right)}$$

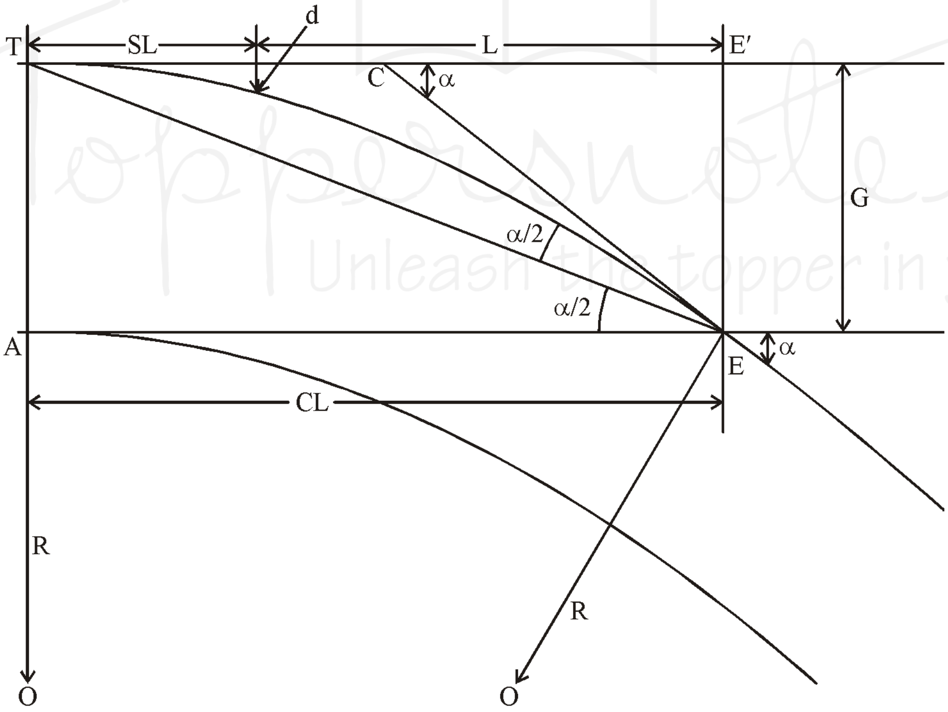
$$c = \frac{Q}{\sin\left(\frac{\alpha+\beta}{2}\right)}$$



$$\sin\left(\frac{\alpha-\beta}{2}\right) = \frac{C/2}{R+G/2}$$

$$R+\frac{G}{2} = \frac{C/2}{\sin\left(\frac{\alpha-\beta}{2}\right)}$$

2.25.3 Coles Method



Curve Lead (CL)

In Δ ATE, $CL = G \cot(\alpha/2)$

Also $CL = E'C + CT$

$= E'C + CE$ (as CT = CE)

$= G \cot\alpha + G \operatorname{cosec}\alpha$

$= GN + G(1 + N^2)^{0.5}$

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Switch Lead (SL)

From the equation of the circle,

$$SL^2 + (R - d)^2 = R^2$$

$$SL^2 = (2Rd - d^2)^{0.5}$$

$$\text{Lead (L)} = CL - SL$$

$$= G \cot (\alpha/2) - (2Rd - d^2)^{0.5}$$

Radius of curve (R)

In Δ AOE,

$$OE^2 = OA^2 + AE^2$$

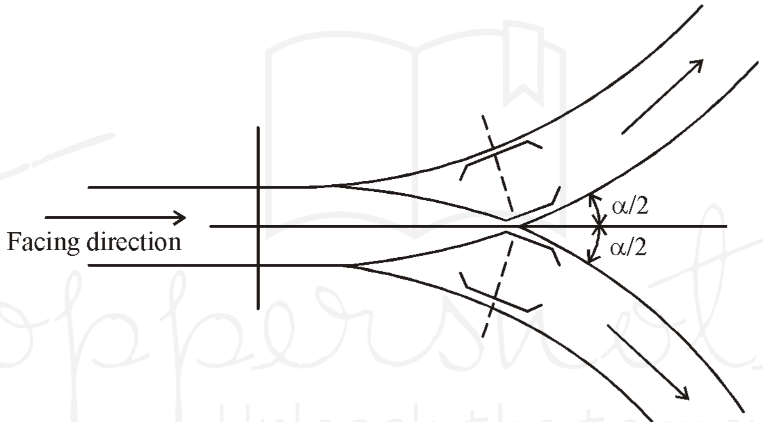
$$R^2 = (R - G)^2 + CL^2$$

$$R^2 = (R - G)^2 + [GN + G (1 + N^2)^{0.5}]^2$$

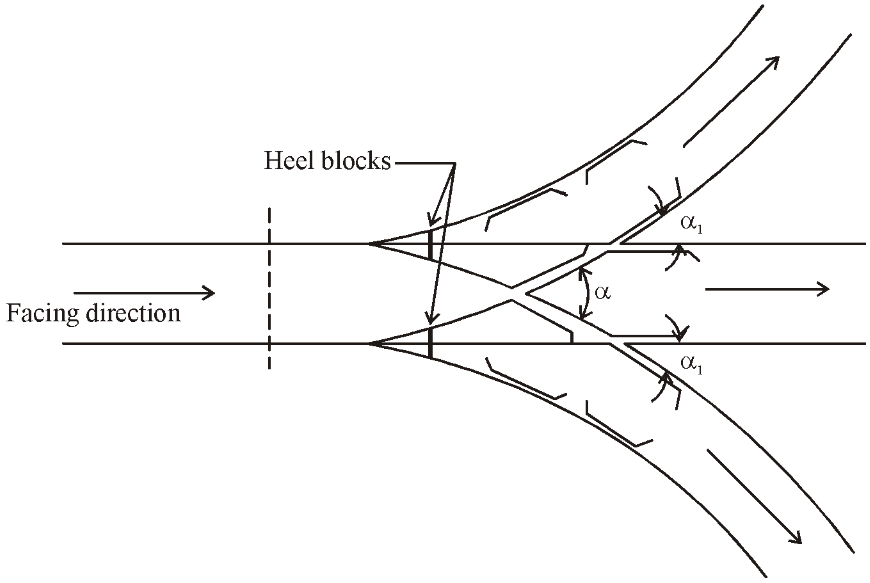
$$R = G(1 + N^2) + GN (1 + N^2)^{0.5}$$

2.26 TRACK JUNCTIONS

Symmetrical Split : When a straight track is split up in two tracks in two different directions with equal radii, it is called symmetrical split.



Three Throw Switch : When two turnouts take off from the same point of a main track, three throw arrangement of the switch is made.



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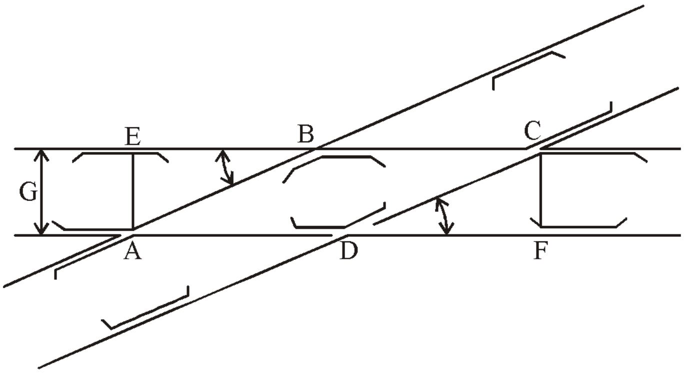
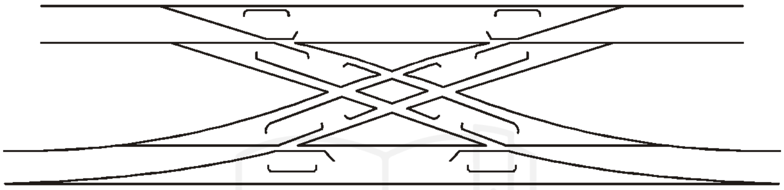
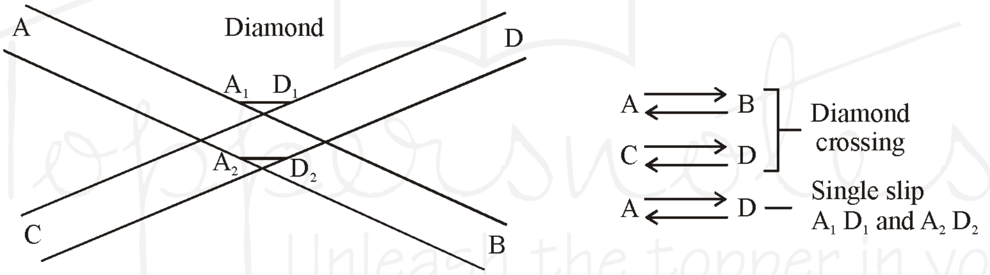
Diamond Crossing : When two tracks cross at an angle less than 90°, a diamond crossing is formed



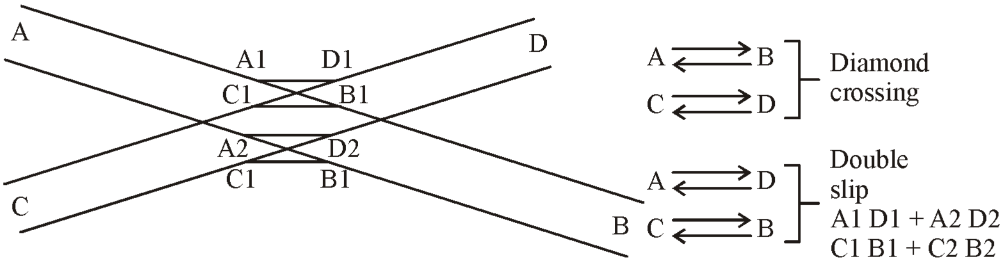
Scissors Crossover : Two parallel tracks are connected by two sets of turnouts. A simple crossover provides change of track by trains moving only in one direction. Scissors Crossover facilitates change over from one track to the other in both the directions.



Single Slip and Double Slip : Single slip and double slip facilitate change over from one track to another on a diamond crossing.



Double Slip :



Double slip

2.27 TRAIN RESISTANCES

Locomotive has to overcome the following resistances

- Train Resistance (Rt)
- Resistance due to track profile (Rg, Rc)
- Resistance due to starting and accelerating
- Wind resistance

The hauling power of the locomotive should be adequate enough to overcome these resistances and pull the train at reasonable speed.

Topper's notes Unleash the topper in you

2.27.1 Train Resistance

These are the resistances the train has to overcome when it is moving on a straight level track at a constant speed in still air. These resistances can be grouped under three categories, viz.,

(a) **Resistance independent of speed (Rt_1) :** This resistance is composed of three different elements :

1. **Rolling resistance**
   - Results from the friction between the wheel tread and the rail head.
   - Though the coefficient of rolling friction between the metals depends on several factors, an average value is adopted for working out this resistance.
2. **Track resistance**

   The wave formation of the rail when an axle moves on it adds resistance to the movement of train. This depends on the weight of axle load
3. **Journal friction proper**
   - This is the resistance that arises from the friction between the journals (turned bearing surfaces) at the end of each axle.
   - Though attempts have been made to derive direct mathematical expressions for train resistance, empirical formula obtained from careful laboratory and field experiments have only become reliable.

$$Rt_1 = 0.0016\ W$$

W = Weight of the train in tonnes

(b) **Resistance dependent of speed (Rt_2) :** The causes of these resistances are the following :

- Track irregularities
- Vertical movement of wheels on rails
- Flange friction, oscillations, sway, etc.
- These resistances increase with increase in speed of the train

$$Rt_2 = 0.00008\ W\ V$$

W = weight of train in tonnes

V = speed of the train in km/hr

(c) **Atmospheric resistance (Rt_3) :** This is the resistance offered by quiet air. This should not be confused with the wind resistance.

$$Rt_3 = 0.0000006\ W\ V^2$$

W = weight of train in tonnes

V = speed of train in km/hr

Therefore, train resistance is the sum of the above mentioned three resistances

$$Rt = Rt_1 + Rt_2 + Rt_3$$

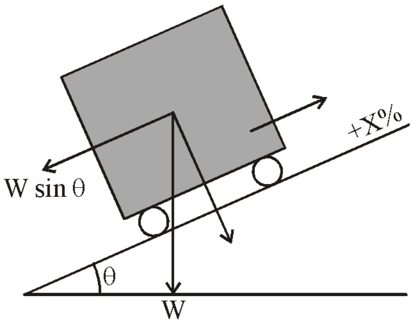
2.27.2 Resistances Due to Track Profile

These are the resistances to be overcome because of gradients and horizontal curves.

Grade resistance (R_g) : A train negotiating a rising gradient has to over come additional resistance equivalent to the component of its weight parallel to the slope.

Curve Resistance (R_c) : This is the additional resistance the train has to overcome when it negotiates a horizontal curve.

Grade Resistance (R_g) : If W = weight of train and θ = angle of slope, then Extra pull required,



$$R_g = W \sin\theta \approx W \tan\theta$$
$$= W \times \text{gradient} = W \times (x/100)$$

Where, x = gradient in percent

2.27.3 Curve Resistance (R_c)

Curve resistance can be determined by the following formula

$$R_c = \frac{FG}{R}$$

Where, F = force of sliding friction

G = gauge distance

R = radius of the curve

However, the following empirical formula are used on Indian Railways

$$R_c = 0.0004\ WD, \text{ for BG}$$
$$= 0.0003\ WD, \text{ for MG}$$
$$= 0.0002\ WD, \text{ for NG}$$

2.27.4 Resistance due to Starting and Accelerating

Resistance on starting

$$R_s = 0.15\ W_1 + 0.005\ W_2$$

Where, W_1 = weight of locomotive in tonnes

W_2 = weight of vehicle in tonnes

Resistance due to acceleration

$$R_a = ma = 0.028\ Wa$$

Where, W = weight of locomotive and vehicle in tonnes

a = acceleration in km/hr/s

2.27.5 Wind Resistance (R_w)

Wind resistance consists of side resistance, head resistance, and tail resistances. Generally wind resistance depends up on the size and shape of vehicle, its speed and intensity and direction of wind. Wind resistance can be obtained by the following formula

$$R_w = C_a AV^2$$

Where, A = exposed area of vehicle in m^2

V = speed of train relative to wind in km/hr

C_a = Constant (= 0.00017 for getting R_w in tonne force).

2.28 HAULING CAPACITY OF A LOCOMOTIVE

Hauling Capacity (HC) of a locomotive depends up on the weight on driving wheels and the coefficient of friction between the driving wheel and the rail.

$$\text{HC} = \text{Coefficient of friction} \times \text{Weight on driving wheels}$$

i.e.,

$$\text{HC} = \mu \times n \times W$$

Where, μ = coefficient of friction

n = number of driving wheels/axles

W = weight on each driving wheel/axle

Coefficient of friction depends on the speed of locomotive and condition of the rail surface. A value between 0.1 (for high speeds) and 0.2 (for low speeds) can be used. A design value of 0.167 is used while working out the Hauling Capacity.

2.29 SIGNALLING ON INDIAN RAILWAY TRACK

Signals on Indian Railway Track can be classified based on the following characteristics

(a) Operational characteristics

1. **Detonating signals (fog/audible signals) :** It draws attention of the driver to the proximity of signal and are placed 400 to 500 m ahead of the signal.
2. **Hand signals :** The flags (red, yellow, green) or lamps with glass slides of red, yellow and green colour can be used. Other type of hand signals are
   - Fixed signals
   - Semaphore signals
   - Colour light signals

(b) Functional characteristics

1. **Stop signals**

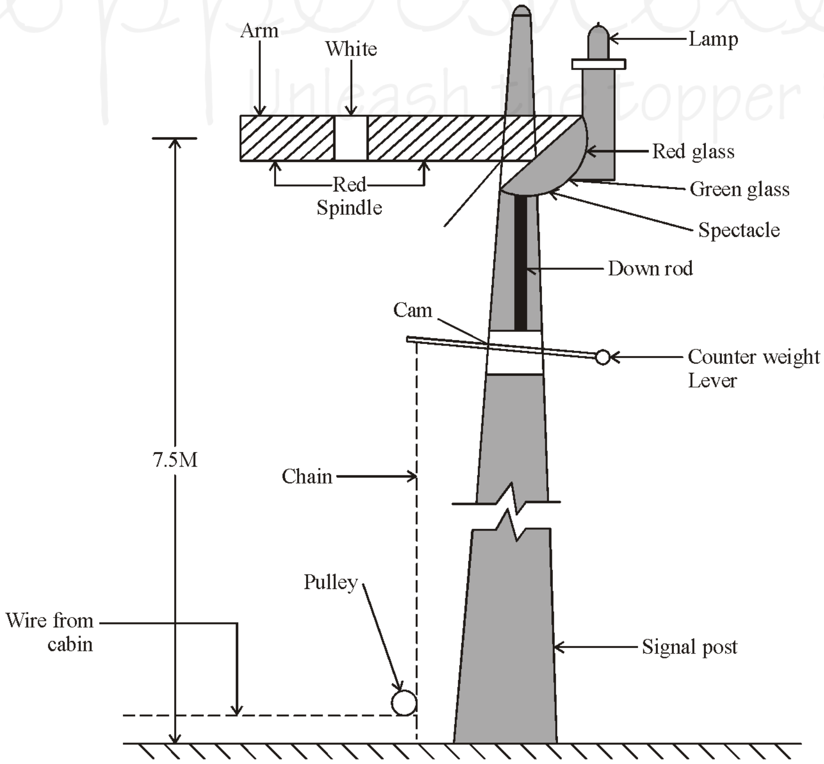
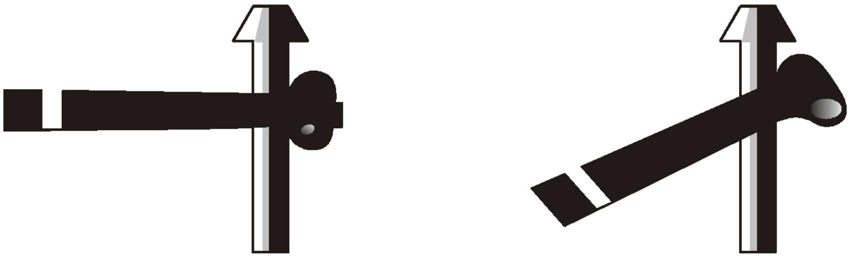


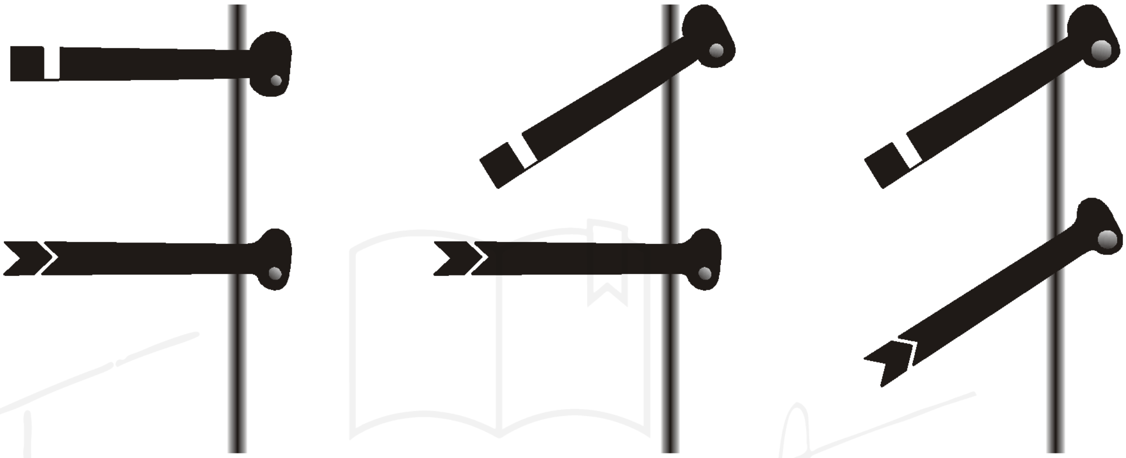
Fig. : Semaphore stop signal



Stop Proceed

Fig. : Indications of semaphore arm

2. Warner signals



Combination warner Stop

Combination warner Caution

Combination warner Proceed

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Fig. : Indications of a warner signal

3. Shunting signals

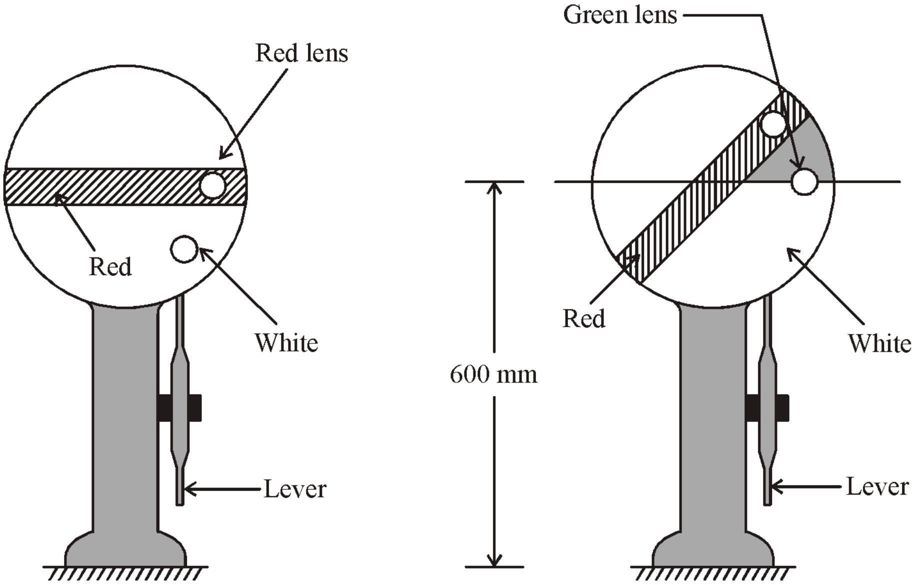

Fig. : Shunting signals

2.30 LINE CAPACITY AND PERSON CAPACITY

Line capacity (T) is the maximum number of trains that can be operated over a section of track in a given period of time, typically 1 hour. Ideally, the combination of the train signaling system being used and the station with the longest dwell time will control the line capacity.

Person capacity (P) is the maximum number of people that can be carried in one direction over a section of track in a given period of time, typically 1 hour, under specified operating conditions without unreasonable delay, hazard, or restriction, and with reasonable certainty.

2.30.1 Number of Cars and Car Capacity

(a) **Number of cars per train (N_c) :** The number of cars in a train is a major determinate of person capacity. The number of cars depends on the length of platform, block length and supply of cars.

(b) **Car Capacity (P_c) :** The number of persons that can be accommodated in a car. This a design standee density (usually 4 persons/m^2). The number of standees is worked out by multiplying the design standee density with the area available for standees.

2.30.2 Peak Hour Factor

Peak hour factor addresses the unevenness of demand over peak hour

$$\text{PHF} = \frac{P_h}{4P_{15}}$$

Where, PHF = peak hour factor

P_h = Passenger volume during the peak hour (P)

P_{15} = Passenger volume during the peak 15 minutes (P).

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